

PRESENTATION TO THE THE SIXTEENTH ANNUAL DEPARTMENT OF DEFENSE COST ANALYSIS SYMPOSIUM

TITLE: ASSESSMENT OF AVIONIC EQUIPMENT FIELD RELIABILITY AND MAINTAINABILITY AS FUNCTIONS OF UNIT COST

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I. INTRODUCTION

Pound-for-pound, avionics is generally recognized as the most expensive, complex and sophisticated part of an air-craft. In some modern aircraft, the avionics may cost as much as 30 percent of total flyaway cost, and avionic support costs for some older aircraft reportedly approach three-fourths of total support cost [1].

Reliability and maintainability are critical characteristics that influence spares provisioning, maintenance resource requirements, system operational availability and, ultimately, investment and operating costs. Consequently, much attention has been focused upon improving the reliability and maintainability of avionics which, in the past, have been disappointingly low. Mr. Norman R. Augustine, a vice-president of Martin Marietta Aerospace, who served as Under Secretary of the Army and Assistant Director of Defense Research and Engineering in OSD, has reflected this disappointment in one of his published tongue-in-cheek "laws" based, in part, on an IDA study done in 1973. His law Number XIX states:

If you are willing to spend enough money on an item of electronics, you can virtually guarantee that it cannot be made to work.

But perhaps things are not quite that bad.

The paper, I am presenting, co-authored by Mr. Joseph W. Stahl and me, addresses avionics reliability and maintainability. The analysis was performed last year in partial response to a

¹ Numbers in brackets are keyed to the list of references at the end of this paper.

request of IDA by OASD (C⁽³I) to provide information for use by DSARC principals at the Full-Scale Development milestone. Since the 5000 series of DoD Directives and Instructions emphasize analytical comparisons of any new system under consideration by the DSARC with current, comparable systems, we undertook analyses to determine if there may be one or more historical relationships between field reliability and maintainability and avionic equipment characteristics that would assist in forecasting those attributes.

The remainder of this paper is devoted to discussion of analyses and findings that:

- Suggest and exemplify methods for projecting field reliability and maintainability of avionic systems,
- Show predictive relationships between field reliability and avionic equipment unit cost, and maintainability and unit cost,
- Demonstrate that field reliability and maintainability vary with the level of technology incorporated in avionic equipment,
- Illustrate, by example, why the reliability of avionics in the field invariably has been lower than demonstration and qualification tests indicate.

II. THE DATA BASE

Our historical data base comprises the hardware unit costs and failure and maintenance data for each of 25 Air Force avionic equipments. The cost data are taken from a proprietary data base that represents the 100th unit cost, in FY 1978 dollars, of a number of avionic systems. The failure and maintenance data are from the Air Force Logistic Command's D056 Log reports for the six-month period August 1979 through January 1980 [2].

Regarding reliability and maintainability, this requirement for comparisons with current, comparable systems is contained in paragraphs 16.a. and b., Encl. 4, DoDI 5000.2, March 19, 1980; paragraphs D.1.c.(2), and 2.a.(4) and 3.a.(2) (Encl. 3) DoDD 5000.39, January 17, 1980; and paragraph D.7b., DoDD 5000.40, July 8, 1980.

The cost data base identifies equipments as to hardware technology levels. The two most recent technologies are used in these analyses. The older of the two is identified as Solid State Devices (SSD) while the newer equipments are identified as Micro-Miniaturized and/or Complex Integrated Circuit Devices (MM). They range from low-cost automatic direction finders, radar altimeters and TACAN's, to high-cost radars, computer sets and ECM equipment. Dates of manufacture span the period 1965 to 1978.

The failure and maintenance data are for avionics included in the cost data base and installed in the following aircraft: F-4C, F-4D, F-4E, F-4G, RC-135A, C-130B, C-130E, F-15A, F-15C, C-141A, C-5A, F-111A and F-111E. Not every item of equipment was installed in every aircraft so, for the purpose of this study, where an item of equipment was installed in more than one aircraft, the totals of the reported operating hours, failures, maintenance actions, etc., were computed.

III. FIELD RELIABILITY VS. UNIT COST

It is generally accepted that reliability and unit cost are functions of equipment complexity. If this is so, mean time between failures (MTBF) and unit cost may be assumed to exhibit reasonable correlation. It would follow that since failures generate maintenance actions, relatively good correlation might be expected between MTBF and MTBMA (mean time between maintenance actions) and between MTBMA and unit cost.

Table 1 presents the data used in this reliability analysis. The equipments are not identified so as not to disclose "privileged information."

Time in use is presented in DO56 reports as operating hours. DO56 guidelines [3] prescribe that operating hours shall be computed by multipliers (factors) determined by the Item Managers and applied to reported flying hours. The guidelines acknowledge, however, that the ratio of operating timeto-flying hours normally is 1.00. DO56 report data used in this study bear out the predominant use of 1.00.

Table 1. RELIABILITY AND COST DATA FOR SELECTED AVIONIC EQUIPMENTS

	MTBMA (HOURS)	385.9	47.5	23.7	23.0	27.2	39.0	25.9	26.0	26.3	29.9	15.6	2.9	7.5	8.0
CES	MTBF (HOURS)	805.0	9.69	32.3	50.0	52.2	55.5	70.9	59.3	29.6	57.3	35.0	6.5	13.8	13.8
SOLID STATE DEVICES	UNIT COST (FY-78\$) 100th UNIT	1,800	7,400	14,400	18,100	21,500	23,800	47,900	97,600	140,800	152,000	156,400	338,600	350,700	498,200
	EQUIP. NO.	-	2	3	4	4	9	7	80	6	91	=	12	13	+1
YICES	MTBMA (HOURS)	82.2	122.2	126.0	118.6	173.8	25.9	32.1	28.2	36.8	53.5	8.7			
TED CIRCUIT DEVICES	MTBF (HOURS)	202.7	341.9	244.4	697.5	379.1	1.08	81.6	63.4	86.3	156.6	20.8			
COMPLEX INTEGRATED	UNIT COST (FY-78\$) 106th UNIT	30,000	40,900	42,200	53,000	53,700	87,300	164,600	219,800	235,000	490,000	1,015,900			
	EQUIP. NO.	1	2	3	4	2	9	7	80	6	01	=			

The results of regression analysis, using unit cost as the independent variable and MTBF as the dependent variable, are depicted in Figure 1. Examination of the plot leads to three interesting observations:

Water House

- Field reliability (MTBF) varies inversely with a power of the unit cost for Air Force avionic equipments of the same technology level. Reasonably good correlation is indicated, reinforcing the hypothesis that MTBF is a function of unit cost.
- Two distinct curves reflect the two technology levels represented in the data sample.
- The newer micro-miniaturized technology generally provides higher reliability for a given cost; roughly a factor of five over the older solid-state technology.

A similar regression analysis was performed using MTBMA as the dependent variable. Results are shown in Figure 2. Notably, the three observations made regarding MTBF versus unit cost can be made for MTBMA versus unit cost. The major differences between the MTBF equations and the MTBMA equations for the same technology level are the linear coefficients. The slopes of the equations are nearly the same. This suggests that for a given technology level, if one knows the MTBF or MTBMA, one can approximate the other based on the ratios of the linear coefficients.

The similarity of the MTBF-versus-unit-cost and MTBMA-versus-unit-cost relationships, coupled with reasonably good fits of the data points to the regression lines, prompted exploration of a direct relationship between MTBMA and MTBF. Figure 3. developed from data in Table 1, presents the results of regression analysis of MTBMA as a function of MTBF for all 25 equipments in the data base. The dependence of MTBMA upon

The appendix comprises a discussion of the regression analyses performed in this study.

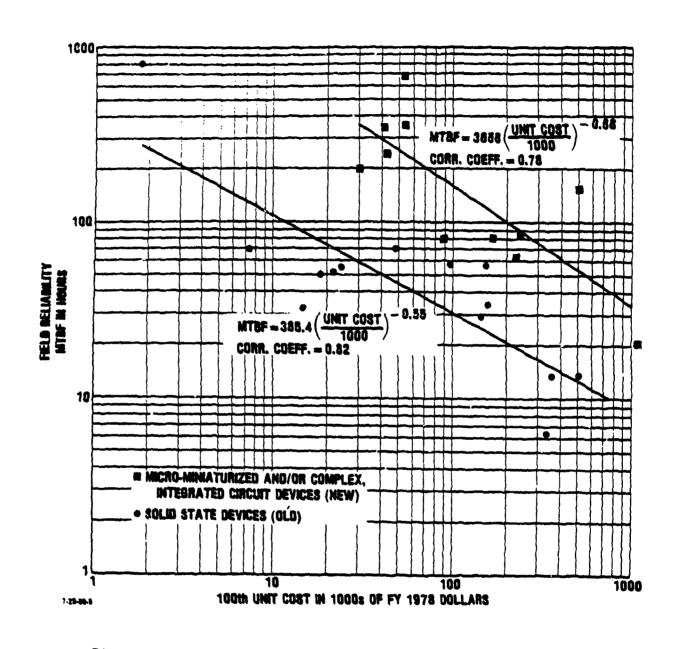


Figure 1. FIELD MTBF VERSUS UNIT COST FOR SELECTED AVIONIC EQUIPMENTS

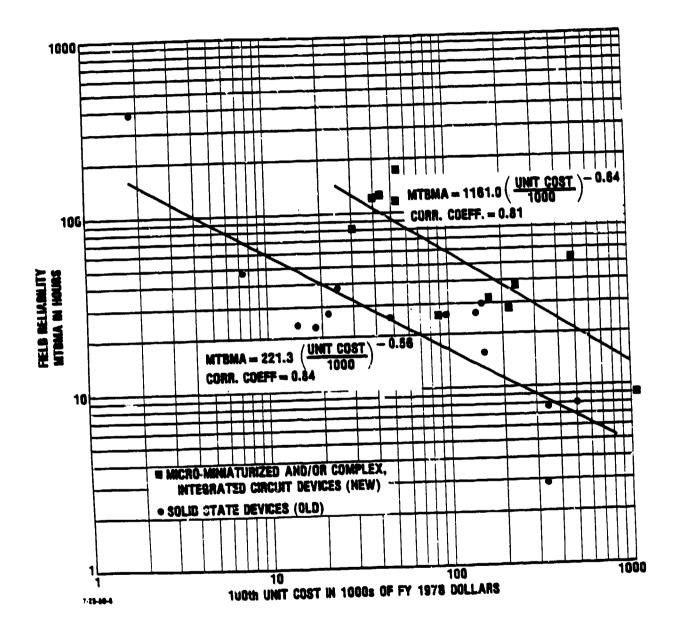


Figure 2. FIELD MTBMA VERSUS UNIT COST FOR SELECTED AVIONIC EQUIPMENTS

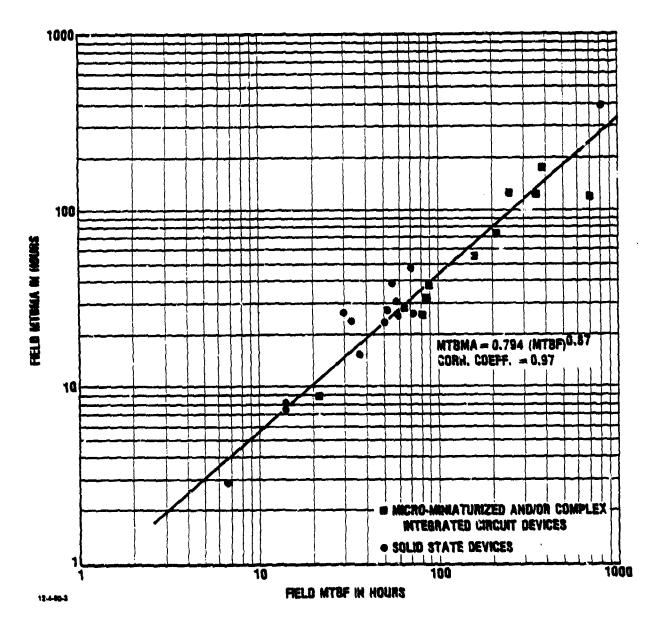


Figure 3. FIELD MTBMA VERSUS FIELD MTBF FOR SELECTED AVIONIC EQUIPMENTS

MTBF constitutes, a priori, a gausal relationship. The degree of dependence, however, is conspicuous in that the strong relationship (r=0.97) appears to hold regardless of the technology level inherent in, or function of, the equipments.

IV. MAINTAINABILITY VS. UNIT COST

In addition to MTBF and MTBMA data, the D056 Log report contains maintenance man-hours for scheduled, unscheduled and shop maintenance actions at the organizational and intermediate (i.e., "shop") levels of maintenance. This information enabled us to evaluate the maintainability specifications of an avionic system that was to be the subject of a DSARC decision.

Segment Specification was mean corrective maintenance time (MCMT); coincidentally, at the organizational and intermediate levels of maintenance. The MCMT values specified did not include maintenance set-up time, time to gain access to the equipment, nor time to complete reinstallation. The D056 Log report, however, does include those increments of time, making the man-hours shown in that report more representative of the maintenance effort that would be required in the field. We excluded scheduled man-hours given in the D056 Log report from our analyses because (a) the System Segment Specification prescribed that the equipment would not be subject to scheduled maintenance and (b) man-hours expended in scheduled maintenance are independent of failure occurrence.

^{&#}x27;Unscheduled depot maintenance man-hours are not included in the DO56 Log Report.

²Although the need for unscheduled depot maintenance was recognized in the Integrated Logistic Support Plan, MCMT at depot level was not addressed in the System Segment Specification.

Inexplicably, programed (i.e., scheduled) depot-level man-hours are included in shop (i.e., intermediate-level) man-hours. The AFLC office responsible for the D056 Log Report [4] attributed less than five percent of reported shop man-hours to programed depot-level avionics (continued on next page)

Table 2 contains the data used for the maintainability analysis of the same equipments used in the reliability analyses: equipment failures, maintenance actions, unscheduled man-hours, shop man-hours and unit costs. This information constituted the data base to perform regression analysis using the two variables, unit cost and unscheduled-plus-shop-manhours per failure. Figure 4 illustrates the results. correlation coefficient and the scatter of points about the line representing solid state devices indicate somewhat questionable correlation between man-hours and unit cost. The equation generated by the micro-miniaturized data points yields such poor correlation (r<0.25) that it is not plotted. The scatter of the micro-miniaturized data points illustrates the independence of man-hours per failure and unit cost. In view of these results, the arithmetic means of man-hours per failure for both technologies are shown in Figure 4 as horizontal, dashed lines. They indicate that the average man-hours per failure for the micro-miniaturized equipments is about twice that of the older solid-state technology devices. This observation, coupled with the foregoing analysis of field reliability, suggests that although the equipments typified by the advanced technology fail less frequently, they require more man-hours per failure to repair.

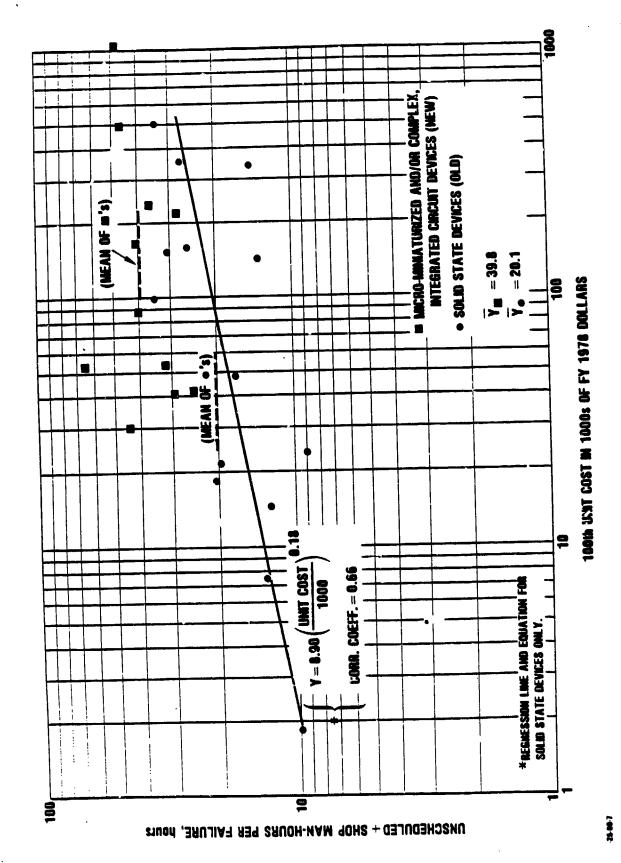
Performing regression analysis using maintenance manhours per maintenance action results in relatively poor correlations and relatively large dispersions of points about the regression lines in Figure 5. The arithmetic means, however, indicate that the more advanced micro-miniaturized equipments consume about one-third more man-hours per maintenance action at the organizational and intermediate levels of maintenance as do the older solid-state avionics.

⁽cont'd) maintenance. "Shop" man-hours in the D056 report include time spent on bench checks in which failures were reported but not verified. The same AFTC office advised that such instances account for about five percent of total report shop time. Although available information did not permit selective reductions in the D056 data, calculations revealed that the effects of relevant adjustments to the data would be trivial in the context of these analyses.

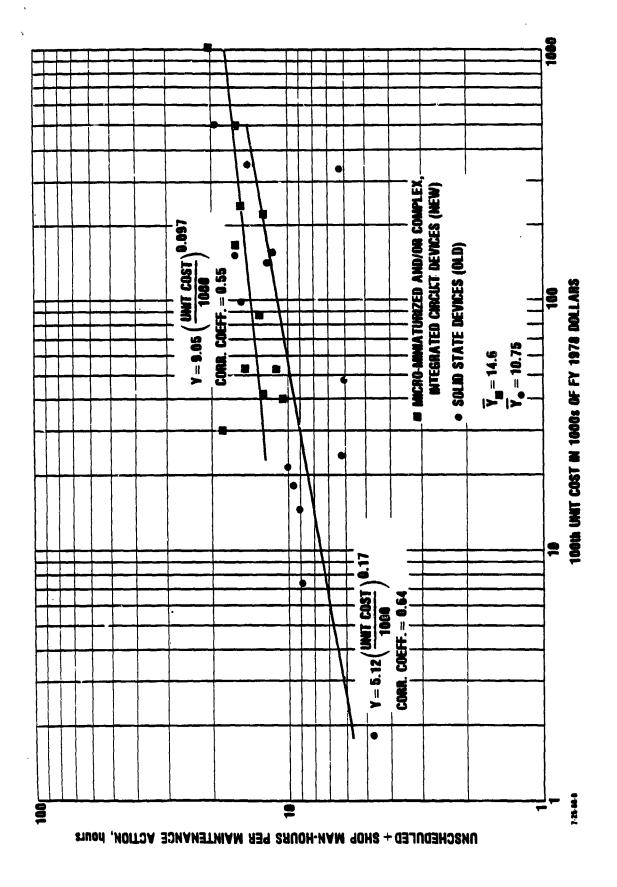
MAINTENANCE AND COST DATA FOR SELECTED AVIONIC EQUIPMENTS Table 2.

date of the control of the c				No. of		Han-Hours		Unscheduled	Unscheduled	Unit Cost
SSD 23 48 172 55 227 9.1.7 4.73 1.73 SSD 2,094 3,070 11,546 15,746 27,292 13.03 8.89 71 SSD 5,14 6,246 27,59 9,044 26,246 9,194 12,54 9,194 11,54 12,64 12,54 9,194 12,64 12,54 9,194 12,64 12,54 9,194 12,54 9,194 12,64 12,54 18,24 12,64 12,64 12,245 8.86 6.10 9,19 11 12,01 18,22 15,37 18,22 12,24 18,24 18,22 18,37 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,24 18,22 12,34 18,22 13,24 13,24 13,24 13,24 13,24 13,24 13,24 13,24 13,24 13,24 13,24 13,24	tguipment No.	lype	No. of Failures	Maintenance Actions	Unscheduled	Shop	Unscheduled + Shop	+ Shop M-Hrs.	+ Shop M-Hrs Maint. Act.	(fY-78 \$) 100th Unit
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SSD 574 783 3,142 4,656 7,196 12.54 9.044 6,245 2,759 9,004 20.56 9,54 \$50 356 680 4,448 2,205 6,453 19.30 10.08 2,54 \$50 2,511 3,516 12,649 2,205 2,245 8.86 6.22 2 \$50 114 260 1,649 2,302 3,971 34.83 15.30 1 6.10 6.10 6.22 2 2 2 2 2,302 3,971 34.83 15.30 1,597 16.30 15.30 1,597 16.10 6.10 6.10 6.10 6.10 6.10 6.10 6.10 16.10 <td< th=""><th>2</th><td>850</td><td>2,094</td><th>3.070</th><th>.546</th><td>15,746</td><td>27,292</td><td>13.03</td><td>8.89</td><td>7,400</td></td<>	2	850	2,094	3.070	.546	15,746	27,292	13.03	8.89	7,400
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NM 153 428 2,392 2,135 4,527 29.59 10.58 NM 214 415 2,147 3,161 5,326 24.90 12.84 NM 75 441 1,548 3,404 4,952 66.03 11.23 NM 138 301 1,705 2,732 4,437 32.15 14.74 NM 653 2,023 10,428 15,779 26,207 40.13 12.95 NM 292 658 3,469 17,375 26,207 40.13 12.95 NM 292 658 3,469 4,752 8,221 28.15 16.10 NM 606 1,420 7,482 14,364 36.05 15.36 NM 2,520 5,982 45,471 77,714 123,185 46.71 15.97	_	ž	852	636	4.272	7,176	11,148	44.37	18.00	30,000
NM 214 415 2,147 3,181 5,326 24.90 12.84 NM 75 441 1,548 3,404 4,952 66.03 11.23 NM 138 301 1,705 2,732 4,437 32.15 14.74 NM 653 2,023 10,428 15,779 26,207 40.13 12.95 NM 641 1,632 8,899 17,375 26,274 40.99 16.10 NM 606 1,420 7,482 14,364 21,846 36.05 15.38 NM 606 1,420 7,482 14,364 21,846 36.05 15.38 NM 2,520 5,982 45,471 77,714 123,185 48.71 15.97	2	£	153	428	2,392	2,135	4.527	29.59	10.58	10,900
MM 75 441 1,548 3,404 4,952 66.03 11.23 MM 138 301 1,705 2,732 4,437 32.15 14.74 MM 653 2,023 10,426 15,779 26,207 40.13 12.95 MM 292 658 3,469 17,375 26,274 40.99 16.10 MM 292 658 3,469 4,752 8,221 28.15 12.49 MM 606 1,420 7,482 14,364 21,846 36.05 15.30 MM 2,520 5,982 45,471 77,714 123,185 46.71 15.97	<u> </u>	£	214	415	2,147	3.161	5,328	24.90	12.84	45,200
HM 138 301 1,705 2,732 4,437 32.15 14.74 HM 653 2,023 10,426 15,779 26,207 40.13 12.95 HM 641 1,632 8,899 17,375 26,274 40.99 16.16 HM 292 658 3,469 4,752 8,221 28.15 12.49 HM 606 1,420 7,482 14,364 21,846 36.05 15.39 HM 2,520 5,982 45,471 77,714 123,185 46,71 15.97 1	•	₹	7.5	143	1,548	3,404	4,952	66.03	11.23	93,000
HH 653 2,023 10,428 15,779 26,207 40.13 12.95 HH 641 1,632 8,899 17,375 26,274 40.99 16.10 HH 626 3,469 4,752 8,221 28.15 12.49 HH 606 1,420 7,482 14,364 21,846 36.05 15.38 HM 2,520 5,982 45,471 77,714 123,185 46.71 15.97 1	•	Ĭ	138	301	1,705	2,732	4.437	32.15	14.74	53,700
NN 641 1,632 8,899 17,375 26,274 40.99 16.10 NN 292 658 3,469 4,752 8,221 28.15 12.49 NN 606 1,420 7,462 14,364 21,846 36.05 15.30 NN 334 977 3,283 12,318 15,601 46.71 15.97 NN 2,520 5,982 45,471 77,714 123,185 48.88 20.59 1	9	ŧ	653	2,023	-	15,779	26,207	40.13	12.95	87,306
NM 292 658 3,469 4,752 8,221 28.15 12.49 NM 606 1,420 7,482 14,364 21,846 36.05 15.38 NM 334 977 3,283 12,318 15,601 46.71 15.97 NM 2,520 5,982 45,471 77,714 123,185 48.88 20.59 1	,	Ē	149	1.632	_	17.375	26,274	40.99	16.10	164,600
NH 606 1,420 7,482 14,364 21,846 36.05 15.38 NM 334 977 3,263 12,318 15,601 46.71 15.97 NM 2,520 5,982 45,471 77,714 123,185 48.88 20.59 1	37	¥	292	859	3,469	4.752	8,221	28.15	12.49	219,808
HH 334 977 3,283 12,318 15,601 46.71 15.97 HM 2,520 5,982 45,471 77,714 123,185 48.88 20.59 1	37	Ξ	909	1,426	7,482	14,364	21,846	36.05	15.30	235,000
2,520 5,582 45,471 77,714 123,185 48.88 20.59 1	9	₹	334	617		12,318	15.601	46.71	15.97	430,000
	=	ŧ	2,520	5,982	_	11.714	123,185	48.88	20.59	

^aSSD = Solid State Devices MM = Micro-MiniatHrized and/or Complex, Integrated Circuit Devices



UNSCHEDULED + SHOP MAN-HOURS VERSUS UNIT COST FOR SELECTED AVIONIC EQUIPMENTS FAILURES Figure 4



UNSCHEDULED + SHOP MAN-HOURS VERSUS UNIT COST FOR SELECTED AVIONIC EQUIPMENTS Figure 5.

Finally, correlation of maintenance man-hours per operating hour and unit cost were prepared. Table 3 presents the data used to develop the maintenance man-hours per operating hour for each piece of equipment. The same man-hours were used as in the previous discussion. The data points and the equations are plotted in Figure 6. The correlation coefficients are much better than those of the previous regressions using man-hours per failure or man-hours per maintenance action. Note that the curve described by the micro-miniaturized (newer technology) points lies below the curve described by the solid-state devices (older technology) points. It has already been shown that although the newer-technology equipments fail less frequently, they require more man-hours per failure to repair. The results of this maintenance-man-hour-per-operating-hour analysis indicate that the improvement in reliability of the newer-technology equipments more that offsets the additional man-hours needed to repair failures at the organizational and intermediate levils of maintenance. 1

V. <u>SUMMARY</u>

The results of these reliability and maintainability analyses can be summarized as follows:

- Field reliability (measured by MTBF and MTBMA) varies inversely with unit cost for avionic equipments of the same technology level.
- Given two avionic devices having the same unit cost, one typified by the newer micro-miniaturized/complex integrated circuit technology, the other by the previous generation solid-state technology:

¹This finding does not imply that all maintainability problems are offset. The need for additional maintenance man-hours per failure could increase aircraft turnaround times or, alternatively, increase maintenance skill requirements.

OPERATING HOURS, MAINTENANCE MAN-HOURS AND COST DATA FOR SELECTED AVIONIC EQUIPMENTS Table 3.

172 55 227 0.0123 100t 1.546 15.746 27.292 0.1872 100t 1.546 15.746 27.292 0.1872 100t 1.546 15.746 27.292 0.1872 1.546 2.205 6.853 0.3866 1.4568 2.205 6.853 0.3700 2.205 1.537 0.2366 1.537 0.2366 1.537 0.2366 1.546 1.537 0.2366 1.546 1.546 1.557 0.2366 1.546 1.557 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.567 0.2366 1.568 0.3366 1.568 1.568 0.3366 1.568 1.568 0.3366 1.568 1.568 0.3366 1.568 1.568 0.3366 1.568			No. of		Man-Hours		Har chody lak	1005
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SSD 145,811 11,546 15,746 27,292 0.1872 1 SSD 18,524 3,142 4,056 7,198 0.3866 1 SSD 18,524 3,142 4,056 7,198 0.3866 1 SSD 18,542 4,648 2,205 6,653 0.1597 2 SSD 6,763 10,115 2205 1,537 0.3862 9 SSD 6,763 1,115 2,205 3,911 0.4586 9 SSD 18,624 5,149 4,831 9,980 0.5882 9 SSD 18,524 4,831 9,980 0.5886 114 SSD 18,524 4,932 13,666 0.7372 15 SSD 18,524 10,444 67,060 171,504 2.2144 33 SSD 18,524 10,444 67,060 171,504 2.7144 33 SSD 18,548 16,186 27,317 45,803	,	880	18,524	172	55	227	0.0123	1,800
SSD 18,524 3,142 4,056 7,198 0.3886 SSD 21,738 6,245 2,759 9,004 0.4142 SSD 18,542 4,648 2,205 6,853 0.3700 SSD 139,288 12,018 10,227 22,245 0.1597 SSD 6,523 1,115 422 1,537 0.2366 SSD 18,524 5,149 4,831 9,980 0.5882 SSD 18,524 67,060 171,504 2.2144 3 SSD 18,524 20,312 16,186 36,498 0.5388 1 SSD 18,524 20,312 16,186 36,498 0.5388 1 SSD 18,524 4,932 13,566 0.7144 3 SSD 18,524 18,486 27,317 45,903 2.4726 4 SSD 18,524 18,486 27,317 45,903 2.4726 4 MM 52,309 1,548	7	850	145.811	11,546	15,746	27,292	0.1872	7,400
SSD 21,738 6,245 2,759 9,004 0.4142 SSD 18,542 4,648 2,205 6,853 0.3700 SSD 139,288 12,018 10,227 22,245 0.1597 SSD 6,523 1,115 422 1,537 0.2366 SSD 18,624 5,149 4,831 9,900 0.5882 SSD 18,524 8,724 4,932 13,666 0.7372 SSD 18,524 8,724 4,932 13,666 0.7372 SSD 18,524 20,312 16,186 36,986 1.9703 SSD 18,524 20,312 16,186 36,986 1.9703 SSD 18,524 20,312 16,186 36,986 1.9703 SSD 18,524 20,312 16,866 36,986 1.9703 SSD 18,524 20,312 16,866 27,317 45,803 2.4726 4 MM 52,309 1,548 2,135	æ	880	18,524	3,142	4,056	7,198	0.3886	14,400
55D 18,542 4,648 2,205 6,863 0.3700 55D 139,288 12,018 10,227 22,245 0.1597 55D 6,523 1,115 422 1,537 0.2356 55D 3,286 908 599 1,507 0.4586 1 55D 18,524 8,724 4,932 13,656 0.7372 1 55D 18,524 104,444 67,060 171,504 2.2144 3 55D 18,524 16,186 36,98 1.9703 3 55D 18,524 4,272 7,176 11,448 0.2144 52,309 1,548 2,732 4,527 0.0665 1MM 52,309 <t< th=""><td>4</td><td>850</td><td>21,738</td><td>6,245</td><td>2,759</td><td></td><td>0.4142</td><td>091.81</td></t<>	4	850	21,738	6,245	2,759		0.4142	091.81
\$550 139,288 12,018 10,227 22,245 0.1597 \$550 6,523 1,115 422 1,537 0.2356 \$550 6,763 1,669 2,302 3,971 0.5882 \$550 18,524 5,149 4,831 9,980 0.4586 1 \$550 18,524 5,149 4,831 9,980 0.5388 1 \$550 18,524 8,724 4,932 13,656 0.7372 1 \$550 18,524 20,312 16,186 36,498 1.9703 3 \$550 18,524 20,312 16,186 36,498 1.9703 3 \$50 18,524 104,444 67,060 171,504 2.2144 3 \$50 18,524 104,444 67,060 171,504 1.9703 3 \$50 18,524 20,312 16,486 27,317 45,803 2.4726 4 \$MM 52,309 1,548 3,404 4	un.	SSD	18,542	4,648	2,205		0.3700	21,500
SSD 6,523 1,115 422 1,537 0.2356 SSD 6,763 1,669 2,302 3,971 0.5882 SSD 3,286 908 599 1,507 0.4586 1 SSD 18,524 8,724 4,932 13,656 0.7372 1 SSD 18,524 8,724 4,932 13,656 0.7372 1 SSD 18,524 20,312 16,186 36,498 1.9703 3 SSD 18,524 20,312 16,186 36,498 1.9703 3 SSD 18,524 104,444 67,060 171,504 2.2144 3 SSD 18,524 104,444 67,060 171,404 1.9703 3 SSD 18,524 18,486 27,317 45,803 2.4726 4 MM 52,309 2,147 3,181 5,328 0.1019 MM 52,309 10,428 15,779 26,274 0.5010 <	•	850	139,288	12,018	10,227	22,245	0.1597	23,800
SSD 6,763 1,669 2,302 3,971 0.5882 SSD 3,286 906 599 1,507 0.4586 SSD 18,524 4,932 13,656 0.7372 SSD 18,524 8,724 4,932 13,656 0.7372 SSD 77,448 104,444 67,060 171,504 2.2144 SSD 18,524 20,312 16,186 36,498 1,9703 SSD 18,524 104,444 67,060 171,504 2.2144 SSD 18,524 104,444 67,060 171,504 2.2144 SSD 18,524 18,486 27,317 45,803 2.4726 MM 52,309 4,272 7,176 11,448 0.2189 MM 52,309 1,548 3,404 4,952 0.0047 MM 52,309 10,428 15,779 26,207 0.5010 MM 52,309 10,428 15,779 26,274 0.0438 <t< th=""><td></td><td>850</td><td>6,523</td><td>1,115</td><td>422</td><td>1,537</td><td>0.2356</td><td>47,900</td></t<>		850	6,523	1,115	422	1,537	0.2356	47,900
SSD 3,286 908 599 1,507 0.4586 SSD 18,524 5,149 4,831 9,980 0.5388 SSD 18,524 8,724 4,932 13,656 0.7372 SSD 77,448 104,444 67,060 171,504 2.2144 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 NM 52,309 4,272 7,176 11,448 0.2189 NM 52,309 1,548 3,404 4,952 0.0865 NM 52,309 1,548 15,779 26,207 0.0947 NM 52,309 10,428 15,779 26,274 0.5010 NM 52,309 10,428 15,779 26,274 0.0438 NM 52,309 7,482 14,354 21,846 0.4176 <td>6</td> <td>880</td> <td>6,763</td> <td>1,669</td> <td>2,302</td> <td>3,971</td> <td>0.5882</td> <td>97,600</td>	6	880	6,763	1,669	2,302	3,971	0.5882	97,600
SSD 18,524 5,149 4,831 9,980 0.5388 SSD 18,524 8,724 4,932 13,656 0.7372 SSD 77,448 104,444 67,060 171,504 2.2144 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 MM 52,309 4,272 7,176 11,448 0.2189 MM 52,309 2,147 3,181 5,328 0.1019 MM 52,309 1,548 3,404 4,952 0.0847 MM 52,309 10,428 15,779 26,207 0.0848 MM 52,309 10,428 15,779 26,207 0.0438 MM 52,309 10,428 14,37 0.4436 0.4136 MM 52,309 7,482 14,364 21,846 0.4176	Gn .	SSD	3,286	906	599	1,507	0.4586	140,800
SSD 18,524 8,724 4,932 13,656 0.7372 SSD 77,448 104,444 67,060 171,504 2.2144 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 NM 52,309 4,272 7,176 11,448 0.2189 NM 52,309 2,147 3,181 5,328 0.1019 NM 52,309 1,548 3,404 4,952 0.0947 NM 52,309 10,428 15,779 26,207 0.5010 NM 52,309 10,428 15,779 26,274 0.5010 NM 52,309 10,428 17,375 26,274 0.5023 NM 52,309 17,375 26,274 0.5023 NM 52,309 17,482 14,356 0.4438 NM 52,309 17,482 14,356 0.4438 NM 52,309	91	850	18,524	5,149	4.831	9,980	0.5388	152,000
SSD 77,448 104,444 67,060 171,504 2.2144 SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 20,312 16,186 36,498 1.9703 NM 52,309 4,272 7,176 11,448 0.2189 NM 52,309 2,147 3,181 5,328 0.1019 NM 52,309 1,548 3,404 4,952 0.0947 NM 52,309 1,705 2,732 4,437 0.0848 NM 52,309 10,428 15,779 26,207 0.5010 NM 52,309 1,705 2,732 4,437 0.5023 NM 52,309 1,748 15,779 26,207 0.5023 NM 52,309 7,482 14,364 0.4136 2 NM 52,309 7,482 14,364 0.4136 0.4436 NM 52,309 45,471 77,714 123,185 2.3549	-	SSD	18,524	8,724	4,932	13,656	0.7372	156,400
SSD 18,524 20,312 16,186 36,498 1.9703 SSD 18,524 18,486 27,317 45,803 2.4726 MM 52,309 4,272 7,176 11,448 0.2189 MM 52,309 2,147 3,181 5,328 0.1019 MM 52,309 1,548 3,404 4,952 0.0947 MM 52,309 1,705 2,732 4,437 0.0848 MM 52,309 10,428 15,779 26,207 0.5010 MM 52,309 10,428 15,779 26,207 0.5023 MM 52,309 10,428 17,375 8,221 0.4438 MM 52,309 7,482 14,364 21,846 0.4176 MM 52,309 3,283 12,318 15,601 0.2982 MM 52,309 45,471 77,714 123,185 2.3549 1,00	12	SSD	77.448	104,444	67.060	171,504	2.2144	338,600
NM 52,309 4,272 7,176 11,448 0.2189 NM 52,309 2,392 2,135 4,527 0.0865 NM 52,309 2,147 3,181 5,328 0.1019 NM 52,309 1,548 3,404 4,952 0.0947 NM 52,309 1,705 2,732 4,437 0.0848 NM 52,309 10,428 15,779 26,207 0.5010 NM 52,309 1,765 2,732 4,437 0.5023 1 NM 52,309 10,428 17,375 26,207 0.5023 1 NM 52,309 3,469 4,752 8,221 0.4438 2 NM 52,309 3,283 12,318 15,601 0.2982 4 NM 52,309 45,471 77,714 123,185 2.3549 1,00	13	250	18,524	20,312	16,186	36,498	1.9703	350,700
MM 52,309 4,272 7,176 11,448 0.2189 MM 52,309 2,147 3,181 5,328 0.1019 MM 52,309 1,548 3,404 4,952 0.0947 MM 52,309 1,705 2,732 4,437 0.0848 MM 52,309 10,428 15,779 26,207 0.5010 MM 52,309 17,375 26,207 0.5023 1 MM 18,524 3,469 4,752 8,221 0.4438 2 MM 52,309 7,482 14,364 21,846 0.4438 2 MM 52,309 3,283 12,318 15,601 0.2982 4 MM 52,309 45,471 77,714 123,185 2.3549 1,0	14	OSS	18,524	18,486	27,317	45,803	2.4726	498,200
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NM 52,309 2,147 3,181 5,328 0.1019 NM 52,309 1,548 3,404 4,952 0.0947 NM 52,309 1,705 2,732 4,437 0.0848 NM 52,309 8,899 17,375 26,207 0.5010 NM 18,524 3,469 4,752 8,221 0.4438 2 HM 52,309 7,482 14,364 21,846 0.4176 2 NM 52,309 3,283 12,318 15,601 0.2982 4 NM 52,309 45,471 77,714 123,185 2.3549 1,0	2	ž	52,309	2,392	2,135	4,527	0.0865	40,900
NM 52,309 1,548 3,404 4,952 0.0947 NM 52,309 1,705 2,732 4,437 0.0848 NM 52,309 10,428 15,779 26,207 0.5010 NM 52,309 8,899 17,375 26,274 0.5023 1 NM 52,309 7,482 14,364 21,846 0.4176 2 NM 52,309 45,471 77,714 123,185 2.3549 1,0	m	Ē	52,309	2,147	3,181	5,328	0.1019	42,200
NM 52,309 1,705 2,732 4,437 0.0848 NM 52,309 10,428 15,779 26,207 0.5010 NM 18,524 3,469 4,752 8,221 0.5023 NM 52,309 7,482 14,364 21,846 0.4176 NM 52,309 3,283 12,318 15,601 0.2982 NM 52,309 45,471 77,714 123,185 2.3549	•	ž	52,309	1,548	3,404	4,952	0.0947	53,000
NM 52,309 10,428 15,779 26,207 0.5010 NM 18,524 3,469 17,375 26,274 0.5023 NM 18,524 3,469 4,752 8,221 0.4438 NM 52,309 7,482 14,364 21,846 0.4176 NM 52,309 45,471 77,714 123,185 2.3549	vo.	ž	52,309	1,705	2,732	4,437	0.0848	53,700
NM 52,309 8,899 17,375 26,274 0.5023 NM 18,524 3,469 4,752 8,221 0.4438 NM 52,309 7,482 14,364 21,846 0.4176 NM 52,309 3,283 12,318 15,601 0.2982 NM 52,309 45,471 77,714 123,185 2.3549	•	Ŧ	52,309	10,428	15,779	26,207	0.5010	87,300
HM 18,524 3,469 4,752 8,221 0.4438 HM 52,309 7,482 14,364 21,846 0.4176 HM 52,309 3,283 12,318 15,601 0.2982 HM 52,309 45,471 77,714 123,185 2.3549	7	Ŧ	52,309	8,899	17,375	26,274	0.5023	164,600
MM 52,309 7,482 14,364 21,846 0.4176 MM 52,309 3,283 12,318 15,601 0.2982 MM 52,309 45,471 77,714 123,185 2.3549	80	Ŧ	18,524	3,469	4,752	8,221	0.4438	239,800
HH 52,309 3,283 12,318 15,601 0.2982 HH 52,309 45,471 77,714 123,185 2.3549	σ,	¥	52,309	7,482	14,364	21,846	0.4176	235,000
52,309 45,471 77,714 123,185 2.3549	01	Ŧ	52,309	3,283	12,318	109,21	0.2982	490,000
	=	Ŧ	52,309	45,471	77,714	123,185	2.3549	1,015,900

aSSD = Solid State Devices
NM = Micro-Miniaturized and/or Complex, Integrated Cfrcuit Devices

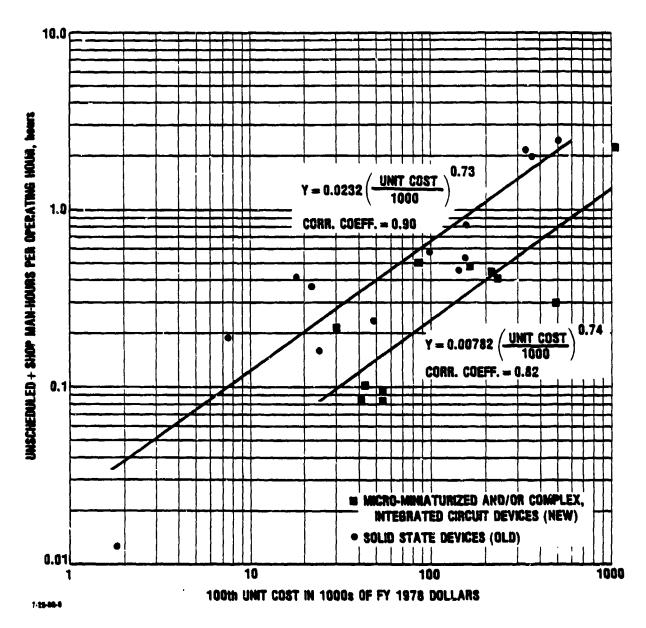


Figure 6. UNSCHEDULED + SHOP MAN-HOURS VERSUS UNIT COST FOR SELECTED AVIONIC EQUIPMENTS

- The field reliability of the equipment characterized by the newer technology would exceed that of the older technology by a factor of five....however.
- Given a failure, the equipment incorporating the newer technology may consume twice as many man-hours to repair at the organizational and intermediate levels.
- Maintenance man-hours expended per operating hour at the organizational and intermediate levels on avionics typified by the newer technology approximates 40 percent of the man-hours devoted to avionics incorporating the older technology.

Regarding the results of the foregoing reliability analyses, we fully expect that the quantitative values (e.g., the equations and correlation coefficients) would change somewhat with enlargement and refinement of the data base. We believe, however, that the trends and relationships, as stated qualitatively in our findings, are unmistakable.

The results of our maintainability analyses are less satisfying. Although indicative of the organizational and intermediate levels of maintenance, consideration of unscheduled depot-level maintenance is needed to attain more complete understanding.

VI. TEST MTBF VS. FIELD MTBF

In the course of our study of the avionic system approaching a DSARC milestone, some DoD officials concerned with the system frequently referred to an MTBF value given in the System Segment Specification, which referenced the applicable reliability test MTL STD, as expected field MTBF. In fact, that MTL STD [5] specifies that the MTBF value is "...for the purpose of establishing accept/reject criteria and shall not be used for projection of equipment MTBF."

The fallacy ling the results of demonstration, development, or qualification tests as representative of expected field reliability is exemplified by the Failure Tree in Figure 7. The reliability demonstrated for a similar avionic system by the FSD contractor is used as the example. Note that the 325-hour

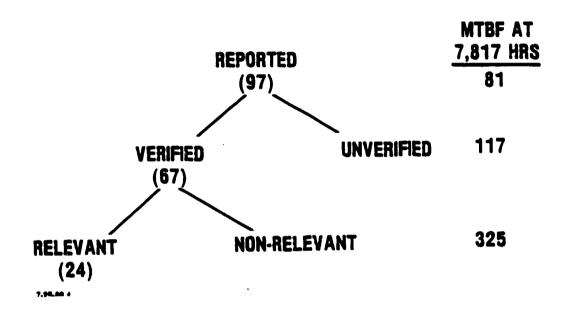


Figure 7. FAILURE TREE

MTBF in the column on the right is based on relevant failures; ¹ and relevant failures, by contractual agreement, were the basis for determination of the contractor's compliance with reliability specifications. Actually, 97 failures were initially reported as equipment failures, of which 67 were verified as equipment failures. Of the 67, only 24 were eventually classified as relevant, yielding by contractual definition, an MTBF of 325 hours.

In deployed operational units, however, discrimination between relevant and non-relevant failures is immaterial. Each perceived (i.e., "reported") failure generates a maintenance action and each verified failure frequently generates spares requirements and additional maintenance effort. With reference to the example in Figure 7, the DO56 Log report would have shown a 117-hour MTBF; about one-third of the 325-hour MTBF resulting from contractual definition. Obviously, the indiscriminate use of the acronym "MTBF" can be grossly misleading, especially in planning for O&S resources for new avionic systems.

¹Testing was conducted consistent with MIL-SID-781B, which defined relevant failures as those attributable to the contractor's performance (e.g., design, workmanship and premature part failure). Discrimination between relevant and non-relevant failures, however, are subject to negotiation.

REFERENCES

- [1] Air Force Audit Agency, Department of the Air Force, Summary Report of Audit, Impact of New Management Concepts on Support and Maintainability of Avionic Equipment (87381), 23 March 1979.
- [2] Maintenance Actions, Manhours and Aborts by Work Unit Code for Various Aircraft, AFLC-PCN D056B5006, RCS: Log-MMO (AR) 7170, August 1979-January 1980.
- [3] Air Force Logistic Command, Maintenance Actions, Manhours and Aborts by Work Unit Code, PCN: D056B5006, 1 July 1976.
- [4] Headquarters, Air Force Logistics Command (AFLC/LOEP), Wright-Patterson AFB, Ohio.
- [5] MIL-STD-781C, Military Standard, Reliability Design Quilification and Production Acceptance Tests; Exponential Distribution, AMSC No. 22333, Department of Defense, 21 October 1977.

APPENDIX

REGRESSION ANALYSIS METHODOLOGY

REGRESSICN ANALYSIS METHODOLOGY

In simple linear correlation the correlation coefficient (r) is a parameter commonly applied to test the "goodness of fit" of the data points used to generate a straight (regression) line by the method of least squares. A correlation coefficient of l (i.e., perfect correlation) would mean that all points used to describe the regression line fell on the line, and that estimates made from the line (or its equation) would be without error. Although "goodness of fit" should not be confused with causality, normally the closer r is to l, the higher the confidence that can be placed in estimates that fall within the range of the data. The square of the correlation coefficient, named the index (or coefficient) of determination, indicates the proportion of variation in the dependent variable (Y) that can be explained in terms of the independent variable (X).

Regression analyses were performed on historical cost, reliability and maintainability data to determine if relationships between cost and the reliability and maintainability variables could be developed. The regression analyses were performed on the General Electric (GE) Time Sharing System, using the standard GE program CURFT\$. The program executes "...a regression analysis on bivariate data, calculating regression coefficients and an index of determination for each of six curve types." 1

¹ User's Guide Statistical and Mathematical Programs, General Electric Report 5700.01, October 1971.

It was decided to utilize throughout this Paper the one curve type of the six in the G.E. program that yielded the best fit most often. Outputs of the G.E. program were examined and, through ranking the values of the correlation coefficients for the six curve types for all of the regressions, the power form (Y=AXD) was indicated as the choice. The power form is a nonlinear equation, however, and the G.E. program transforms the input data, as necessary, so that the equation derived from those data is expressed in linear form to enable linear correlation. To obviate the effect of data transformation, we examined the values of the means and the standard deviations of the differences between the actual values of the dependent variables and the values calculated for those variables from the regression equations generated by the G.E. program. The resulting values of standard deviation were then ranked, as before, to select the most representative curve type. Again, the power form was indicated as the choice; accordingly, it was used throughout this Paper. The reader should be aware that the regression equations, correlation coefficients, and figures in the main text reflect the data transformation performed by the G.E. program. This fact does not diminish the validity of the analyses.

¹Standard deviations were computed using the unbiased estimator; that is, the sum of the squared deviations was divided by (n-1) rather than (n).